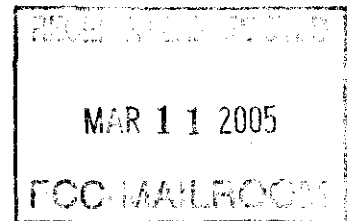


Before the
Federal Communications Commission
Washington, D.C. 20554



In the Matter of

Facilitating Opportunities for Flexible, Efficient,
and Reliable Spectrum Use Employing Cognitive
Radio Technologies

ET Docket No. 03-108

REPORT AND ORDER

Adopted: March 10, 2005

Released: March 11, 2005

By the Commission: Commissioner Adelstein issuing a statement.

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I. INTRODUCTION

1. Advances in technology are creating the potential for radio systems to use radio spectrum more intensively and more efficiently than in the past. Perhaps none of these advances holds greater potential for literally transforming the use of spectrum in the years to come than the development of software-defined and cognitive, or "smart," radios. Regardless of the regulatory model – licensed,

unlicensed, or other new models – these technologies are allowing and will increasingly allow more intensive access to, and use of, spectrum than possible with traditional, hardware-based radio systems.

2. Software defined and relatively simple cognitive radio systems are already in use today. They include current cellular radio systems with capabilities such as transmit power control, handoff reconfiguration, and real time network control such as registration and control channel signaling. In addition, wireless local area networks are currently using adaptive techniques for channel identification, dynamic frequency selection, and adaptive modulation schemes for varying data throughput. The Commission has recognized cognitive capabilities in the rules as a means of allowing more efficient spectrum use.¹ Multiple organizations such as the Software Defined Radio Forum and the European Union are dealing with specific technical issues of importance to the deployment of software defined and cognitive radios. Numerous companies, often working with governmental agencies, are actively developing new products to take advantage of these capabilities. For example, one manufacturer has developed and obtained approval for a cellular base station that is designed to be remotely modified by software to enable operation with different modulation formats, thereby allowing a single base station to communicate with handsets employing different transmission formats.² We expect to see additional software-based products with new capabilities over the next few years.

3. Some parties envision that the full development of cognitive radio capabilities will, or should, lead to a vastly different model for spectrum use. These “futurists” see “smart radios” operating on an opportunistic basis, finding idle spectrum, using it as they need, then vacating the band for others to use, all without human intervention. This model presumes no need for spectrum policy, allocation tables, or regulatory bodies to manage spectrum resources. While we recognize that this model exists, we also believe that many technical, cost, and business issues will need to be addressed in the marketplace before widespread deployment of such radios may take place. Therefore, we need not, and do not, address today the potential implications of such a radical paradigm shift. We do need to consider, however, whether the advent of these ongoing developments in software-defined and cognitive or smart radios require changes or clarifications in our current rules and procedures. We neither wish to have our processes inadvertently be a barrier to the development and deployment of these technologies nor wish to permit the widespread deployment of radios easily susceptible of being misused to cause harmful interference to others.

4. In this Report and Order, we thus continue the process of modifying our rules to reflect these ongoing technical developments in radio technologies. When the Commission first adopted rules for software defined radios, it recognized that manufacturers were beginning to use software to help determine the RF characteristics of radios, and that our equipment rules, which assumed hardware changes were needed to modify a radio’s behavior, held the potential of discouraging development of software defined radios by requiring repeated approvals for repeated software changes.³ In light of the Commission’s experience with these rules, and the record in this proceeding, we are here modifying and clarifying our equipment rules to further facilitate the development and deployment of software defined and cognitive radios. Specifically, we are eliminating the rule that a manufacturer supply radio software (source code) to the Commission upon request because such software is generally not useful for

¹ See 47 C.F.R. §§ 15.323 and 15.407(h).

² See *FCC Approves First Software Defined Radio*, News Release dated November 19, 2004.

³ See *First Report and Order* in ET Docket No. 00-47, 16 FCC Rcd 17373, 17377 (2001).

certification review and may have become an unnecessary barrier to entry.⁴ We are requiring that a manufacturer supply a high level operational description of the radio software that controls its RF characteristics for certification of a software defined radio. We are also clarifying our rules to permit manufacturers to market radios that have the hardware-based capability to transmit outside authorized United States frequency bands, but have software controls to limit operation to authorized frequency bands when used in the United States. In addition, we are modifying the rules to ensure that radios with software that is designed or expected to be modified by a party other than the manufacturer have reasonable security measures to prevent unauthorized modifications that would affect the RF operating parameters or the circumstances under which the transmitter operates in accordance with Commission rules. Further, we describe the technical measures that cognitive radios could employ to allow secondary use of spectrum by lessees while maintaining the availability of the spectrum for a higher priority use by the licensee when needed. We conclude that such measures are, or will be, technically feasible, but see no need to adopt any particular technical model for interruptible spectrum use. These actions are taken to facilitate opportunities for flexible, efficient, and reliable spectrum use by radio equipment employing cognitive radio technologies and enable a full realization of their potential benefits.

II. BACKGROUND

5. An accelerating trend in radio technologies has been the use of software in radios to define their transmission characteristics. The incorporation of cognitive radio technologies to allow the more efficient use of spectrum is also becoming increasingly common. As demonstrated in this and earlier proceedings, this Commission has a continuing commitment to recognize these important new technologies and make any necessary changes to its rules and processes to facilitate their development in the public interest.

6. *Development of Cognitive Radio Technologies.* Over the past several years, manufacturers have increased the computer processing capabilities of radio system technologies. As a result, radio systems are increasingly incorporating software into their operating design. Incorporating software programming capabilities into radios can make basic functions easier to implement and more flexible. As the capabilities have advanced, radio systems have been gaining increased abilities to be “cognitive”—to adapt their behavior based on external factors. This “ability to adapt” is opening up a vast potential for more flexible and intensive use of spectrum.

7. Radios traditionally were built with unalterable hardware devices that performed specific functions or operations, such as filters, mixers, amplifiers, and detectors. In certifying these radios, the Commission required circuit diagrams and performance specifications to test and verify compliance. With the development of digital logic and computing devices, software programmable processors could accomplish many of these same radio functions. Radios originally built strictly with hardware became transmitting/receiving devices whose functionality was defined not by the hardware but instead by the software that ran on microprocessors and programmable electronic devices. The software in such a software radio was reconfigurable and could be easily modified or changed so that entirely different functionality could be attained by simply changing the software on a common hardware platform.

8. Modern radios incorporate software to provide new features and functions for consumers, but not all software has an effect on the radio frequency operating parameters of the device. For instance, games, web browsers and ring tones that are used in portable wireless devices normally have no impact

⁴ We always retain the right to request and examine any component (whether software or hardware) of a specific radio system when needed for certification under Commission rules.

on the RF characteristics of the host device. The Commission has never had regulations concerning the use of such software and this proceeding does not address the use of such software. Many modern radios do, however, contain software that affects the radio frequency operating parameters. For quite some time, the transmission characteristics of commercial radios have been controlled by software contained in the firmware embedded in the electronics of the radio. But, by virtue of this design, software changes that might alter a radio's RF characteristics can not be easily made after the device is manufactured.

9. More recently, many radios have begun to incorporate microprocessors and digital electronics that produce radio signals whose operating parameters such as frequency and modulation type are determined by the software that runs on the microprocessor. Under our rules, such "software defined radios" include any "radio that includes a transmitter in which the operating parameters of frequency range, modulation type or maximum output power can be altered by making a change in software without making any changes to hardware components that affect the radio frequency emissions."⁵ In such software defined radios, the radio can be programmed to transmit and receive on any of a variety of frequencies and/or to use one or more different transmission formats supportable by its hardware design. Until recently, the software installed at the factory that controls the radio frequency operating parameters in most software defined radios is not readily changeable after manufacture. The major advantage of software defined radios with non-modifiable software is to provide for economies in manufacture: the manufacturer can configure the same hardware product into any of a number of radios through software changes alone. Now, manufacturers are producing software defined radios in which the control software is designed or expected to be modified by a party other than the manufacturer. This ability to change software after manufacture potentially affords the user direct control over the radio's capability to operate in a variety of frequency bands and/or to use differing transmission characteristics to access available radio services consistent with the Commission's technical and service rules.

10. A cognitive radio goes one step further, and empowers the radio to alter its transmitter parameters based on interaction with the environment in which it operates. Most commonly implemented through software in a software defined radio,⁶ this interaction may involve active negotiation or communications with other spectrum users and/or passive sensing and decision making within the radio. For instance, using a hardware-based design, a CMRS carrier wanting to install a cellular base station designed to serve multiple modulation formats would have to predetermine a fixed allocation of capacity among each of the supported formats. By contrast, a base station with cognitive radio capabilities could adopt a dynamic allocation of capacity among the different modulation formats on a real-time basis. With software defined radios as an implementation methodology, cognitive radios are now being built that can recognize factors in their environment and modify their performance characteristics by changes made via software defined radio techniques.

11. As radios become more intelligent, they gain greater flexibility and are able to adapt their RF behavior to identify and use spectrum that otherwise would not be available for fear of causing interference. Features that cognitive radios can incorporate to allow for more efficient, flexible spectrum use include.

⁵ See 47 C.F.R. § 2.1.

⁶ Radios with cognitive capabilities do not have to rely on software implementations, however. Cordless telephones, for instance, have long had the capability to select the best channel among a number of authorized channels based on relative channel availability. See also para 12, *infra*.

- **Frequency Agility** - the ability of a radio to change its operating frequency to optimize use under certain conditions
- **Dynamic Frequency Selection (DFS)** – the ability to sense signals from other nearby transmitters in an effort to choose an optimum operating environment
- **Adaptive Modulation** – the ability to modify transmission characteristics and waveforms to exploit opportunities to use spectrum.⁷
- **Transmit Power Control (TPC)** – to permit transmission at full power limits when necessary, but constrain the transmitter power to a lower level to allow greater sharing of spectrum when higher power operation is not necessary.
- **Location Awareness** - the ability for a device to determine its location and the location of other transmitters, and first determine whether it is permissible to transmit at all, then to select the appropriate operating parameters such as the power and frequency allowed at its location.
- **Negotiated Use** - a cognitive radio could incorporate a mechanism that would enable sharing of spectrum under the terms of a prearranged agreement between a licensee and a third party. Cognitive radios may eventually enable parties to negotiate for spectrum use on an ad hoc or real-time basis, without the need for prior agreements between all parties.

12. Radios with cognitive capabilities are already in use. Some wireless LAN devices and CDMA networks incorporate cognitive capabilities to sense spectrum use and/or to adjust transmit power to allow more efficient spectrum use, although there is no current requirement in the rules to incorporate such capabilities. There are other devices that our rules do currently require to have cognitive capabilities. Unlicensed Personal Communication Service (PCS) devices are required to monitor the spectrum prior to transmission to avoid interference to other unlicensed PCS devices.⁸ Also, Unlicensed National Information Infrastructure (U-NII) devices operating in the 5.25-5.35 GHz and 5.47-5.725 GHz bands are required to incorporate DFS and TPC to avoid interference to Federal Government operations.⁹

13. It is not unreasonable to expect that radios of the future will not only have adaptive cognitive capabilities but also be flexible to the point that they may negotiate with each other under a set of rules or etiquette for operation and can “learn” from their past experience. Some refer to these flexible radios as “ontology radios” or “policy radios” due to their intelligence-based reasoning characteristics.¹⁰

⁷ Heteromorphic waveforms and other new techniques would allow two or more waveforms to co-exist by using different polarity, code, orthogonality, etc.

⁸ See 47 C.F.R. §15.323. The Commission recently allocated the unlicensed PCS band at 1910-1915 MHz to the fixed and mobile service and the unlicensed PCS band at 1915-1920 MHz to Advanced Wireless Service (AWS).

⁹ See 47 C.F.R. § 15.407(h).

¹⁰ From Webster’s Dictionary and artificial intelligence constructs, ontology is an explicit formal specification of how to represent the objects, concepts and other entities that are assumed to exist in some area of interest and the relationships that hold among them. See <http://dictionary.reference.com/search?q=ontology>.

14. *Commission Proceedings on Software Defined Radio and Cognitive Radio Technologies.* In 2001, the Commission adopted changes to the equipment authorization rules to accommodate the developing software defined radio (SDR) technology.¹¹ The Commission defined a software defined radio as a transmitter in which the operating parameters of frequency range, modulation type or maximum output power (either radiated or conducted) can be altered by making a change in software that controls the operation of the device without making any changes in the hardware components that affect the radio frequency emissions.¹² This broad definition covers both radios that have software embedded on chips or implemented in other ways so that the software can not be readily changed by the user, as well as radios that are designed so the software can be easily changed after manufacture. It did not include, however, radios where software was used only to select a particular transmission characteristic among a range of permissible alternatives. For instance, the definition does not encompass a radio whose hardware limits its transmission to permissible frequency ranges, with software selecting a particular transmission frequency within those ranges. The SDR rules were intended to make possible for manufacturers to obtain approval for changes to the operating parameters of a radio resulting from software changes without the need to physically re-label a device with a new FCC identification number in the field. The Commission made the rules permissive, rather than mandatory, thereby permitting a manufacturer the option to his declare a device an SDR at the time of filing for certification, but not requiring the manufacturer to do so. The Commission adopted the following rule changes for SDRs:

- Established a new streamlined procedure for obtaining approval for changes to the operating parameters of SDRs that result from changing the software in the device.¹³ The same FCC identification number may be used when changes are made to an approved device.
- Allowed a device's FCC identification number to be displayed electronically, rather than on a physical label.¹⁴
- Required SDRs to incorporate security features to ensure that only software that is part of an approved hardware/software combination can be loaded into an SDR. The exact methods are left to the manufacturer.¹⁵
- Required manufacturers to supply a copy of the software that controls the operating parameters of a radio to the Commission upon request.¹⁶

15. Vanu, Inc. recently became the first manufacturer to obtain approval from the Commission for a software defined radio under these rules.¹⁷ The Vanu equipment is a wireless GSM base station that uses a general-purpose hardware platform to support multiple wireless services and standards entirely in software. It allows modification of the RF planning and assignment of standards through remote software parameter changes, and supports upgrades to new standards through a software-only

¹¹ See *First Report and Order* in ET Docket No. 00-47, 16 FCC Rcd 17373 (2001).

¹² See 47 C.F.R. § 2.1.

¹³ See 47 C.F.R. § 2.1043(b)(3).

¹⁴ See 47 C.F.R. § 2.925(e).

¹⁵ See 47 C.F.R. § 2.932(e).

¹⁶ See 47 C.F.R. § 2.944.

¹⁷ See *FCC Approves First Software Defined Radio*, News Release dated November 19, 2004.

download.¹⁸ The ability to operate with different modulation formats means that a single base station could communicate with handsets using different transmission formats, potentially allowing communication with a greater number of "roaming" users and potentially resulting in lower costs for wireless carriers and users than if multiple hardware-based transmitters had to be employed.

16. The Commission currently has several pending proceedings that address the use of cognitive radio technologies to improve the efficiency of spectrum use. For example, in two separate proceedings, the Commission proposed to require unlicensed devices to incorporate cognitive features to enable operation in the TV broadcast bands and in the 3650-3700 MHz band without causing interference to licensed users in those bands.¹⁹ In addition, we have recently opened additional opportunities that could tap the potential of cognitive radio technologies in our *Secondary Markets* proceeding.²⁰

17. On December 17, 2003, we adopted a *Notice of Proposed Rule Making and Order* ("Notice") in this proceeding to explore the uses of cognitive radio technology to facilitate improved spectrum access.²¹ The *Notice* addressed: 1) the capabilities of cognitive radios, 2) permitting higher power by unlicensed devices in rural or other areas of limited spectrum use, 3) enabling the development of secondary markets in spectrum use, including interruptible spectrum leasing, 4) applications of cognitive radio technology to dynamically coordinated spectrum sharing, and 5) software defined radio and cognitive radio equipment authorization rule changes. A total of 56 parties filed comments and 14 parties filed reply comments in response to the *Notice*.²²

III. DISCUSSION

18. The growth of wireless services over the past several years demonstrates the vast and growing demand of American businesses, consumers, and government for spectrum-based communications. Spectrum access, efficiency, and reliability have become critical public policy issues. We recognize the importance of new cognitive radio technologies, which are increasingly being used in

¹⁸ See <http://www.vanu.com/news/prs/fcc111504.pdf>.

¹⁹ See *Notice of Proposed Rule Making* in ET Docket No. 04-186, 19 FCC Rcd 10018 (2004) and *Notice of Proposed Rule Making* in ET Docket No. 04-151, 19 FCC Rcd 7545 (2004). In a *Report & Order* also adopted today, we are opening the 3650-3700 MHz band to terrestrial devices that incorporate contention-based technologies, FCC 05-____, ET Docket No. 04-151 (adopted March 10, 2005).

²⁰ See *Report and Order and Further Notice of Proposed Rule Making* in WT Docket No. 00-230, 18 FCC Rcd 20604 (2003) and *Second Report And Order, Order On Reconsideration, And Second Further Notice Of Proposed Rulemaking* in WT Docket No. 00-230, 19 FCC Rcd 17503 (2004).

²¹ See *Notice of Proposed Rule Making and Order* in ET Docket No. 03-108, 18 FCC Rcd 26859 (2003).

²² A list of the parties that filed comments is included in Appendix B. Cornell University filed its reply comments on June 3, 2004, two days after the reply comment deadline of June 1, 2004. Cornell subsequently filed a motion for leave to accept the late-filed reply comments on June 4, 2004, stating that no parties will be prejudiced by the late filing of its reply comments and that they contain substantial and significant arguments that will contribute to reasoned decision making in this proceeding. We are accepting Cornell's late-filed reply comments in the interest of obtaining as complete a record as possible in this proceeding. In addition, we note that several other parties filed *ex-parte* presentations after the close of the reply comment deadline. While the Commission is not obligated to consider the merits of such presentations, we will do so in the interest of obtaining as complete a record as possible in this proceeding.

spectrum-based communication systems and are likely to become more and more prevalent over the next few years. These technologies hold tremendous promise in helping to facilitate more effective and efficient access to spectrum by opening opportunities for spectrum use in space, time, and frequency dimensions that until now have been unavailable. The ability of cognitive radio technologies to adapt a radio's use of spectrum to the real-time conditions of its operating environment offers regulators, licensees, and the public the potential for more flexible, efficient, and comprehensive use of available spectrum while reducing the risk of harmful interference. We are seeking in this proceeding to facilitate opportunities for flexible, efficient, and reliable spectrum use by radio equipment employing cognitive radio technologies. Our goal is to ensure that our rules and policies do not inadvertently hinder development and deployment of such technologies, but instead enable a full market-based realization of their potential benefits.

19. The development of cognitive radio technology has been and will continue to be evolutionary in nature. As the technology evolves, our intent is to delete, change, or adopt rules in phases so as to ensure that our rules facilitate the market-based development and deployment of these technologies. In this Report and Order, we first cover in some detail various wide-ranging efforts being undertaken today by both government and industry to further in the near term the development of cognitive capabilities in software-based radio systems and in the longer term the evolution into fully capable cognitive radio systems.

20. To facilitate the market-based development and introduction of new technologies into the market, we are addressing certain issues in this Report and Order that have arisen with respect to the certification of software-based radio equipment.²³ Based on our experience and the comments in the record, we modify and clarify certain of our rules that address software defined radios to facilitate the market based development of this technology. Specifically, we require radios in which the software that controls the RF operating parameters is designed or expected to be modified by a party other than the manufacturer to comply with the rules for software defined radios, including the requirement to incorporate security features to prevent unauthorized modifications to the software. We also modify the definition of software defined radio to include devices where a software change could make the device non-compliant with the Commission's radio frequency emission rules. We are eliminating the rule that the manufacturer supply radio software (source code) to the Commission upon request for certification because such software is generally not useful for certification review and may have become an unnecessary barrier to entry. We always retain the right to request and examine any component (whether software or hardware) of a specific radio system when needed for certification under Commission rules. We are requiring that the manufacturer supply a functional description of the radio software that controls its RF characteristics and a description of the means that will be used to protect that software from unauthorized tampering. Furthermore, since these descriptions are apt to involve proprietary intellectual property, we will make provisions to keep these specific items confidential, for Commission use only.

21. This Report and Order also considers the technical measures that a cognitive radio could incorporate to enable secondary use of spectrum, yet allow the use of such spectrum to quickly and reliably revert back to the licensee when necessary. We conclude that such measures are, or will be, technically feasible, but see no need to adopt any particular technical model for interruptible spectrum leasing.

²³ See *FCC Approves First Software Defined Radio*, News Release dated November 19, 2004.

22. In the *Notice* we proposed to allow unlicensed devices that employ cognitive radio technologies to operate at higher power in rural and other areas with limited spectrum use.²⁴ While we are not adopting any changes to allow higher power operation by unlicensed devices in this Report and Order, we continue to believe that cognitive radio technologies hold great promise to allow such higher power operation without interference to other spectrum users. We expect to further consider the issue of higher power unlicensed operation at a later date.

23. We also sought comment in the *Notice* on what tests might be needed to assure the compliance of licensed and unlicensed devices with any new rules for cognitive radio devices.²⁵ We listed a number of tests that we believed may be necessary for various types of cognitive radio devices. Upon further consideration, we do not believe that it is practical to develop generalized test procedures for cognitive radio devices because the functions that would need to be tested will vary depending on the specific application. Rather, we expect to develop test procedures on a case-by-case basis when new cognitive radio rules are developed, as is being done in the U-NII proceeding.

24. We received a number of comments from parties in response to the *Notice*, principally from commercial mobile radio service (CMRS) interests, that expressed concern that the Commission intended to adopt rules permitting involuntary sharing of licensed CMRS spectrum with unlicensed devices.²⁶ We did not propose to allow such sharing in the *Notice* in this proceeding and we are not adopting any changes herein that would allow such sharing.

A. Cognitive Radio Technology Developments

25. The efforts being undertaken by industry, often working with governmental agencies, standards bodies, and others to research, develop, and implement various software-defined radio and cognitive radio capabilities have been striking. These accomplishments were made possible through various advanced radio technologies such as those of the Department of Defense Joint Tactical Radio System (JTRS) in development of a common software architecture and the first actual software defined radios. Industry, working in conjunction with the military, is also taking a lead in developing and implementing new technologies and is serving as the impetus for further technical developments that should spur the commercial deployment of SDRs and cognitive radios. In addition, efforts are underway within industry forums and standards organizations to adopt internationally accepted standards for software defined radios and cognitive radios. These efforts and the resultant technical developments undoubtedly will lead to even greater flexibility in the future, with some touting the ultimate adoption of radios incorporating a cognition cycle as the foundation for a fully flexible cognitive radio.

26. A key player in the early development software defined radio was the US Department of Defense with its Joint Tactical Radio System (JTRS) Program. This program was intended to develop a software architecture that could be used by all radio developers. Using a common architecture, modular hardware devices and software programs could be built that could be flexibly and interchangeably used in a common architectural framework, yielding reduced radio development and integration costs. The

²⁴ See *Notice* at 26871.

²⁵ See *Notice* at 26896.

²⁶ See V-Comm L.L.C. reply comments at 3-4, Verizon Wireless comments at 2, AT&T Wireless reply comments at 3-4, Cingular/Bellsouth comments at 5, CTIA comments at 5-7, Nokia comments at 2, Nextel Partners comments at 3, and Wireless Communication Association comments at 6.

architecture became known as the Software Communications Architecture (SCA) and is currently in release as version 3.0.²⁷ This software architecture provides a common framework for operational flexibility, interoperability, reduced acquisition costs and enhancement via technology insertion. The SCA is defined as "the architectural concept that defines the essential core set of open software interfaces and profiles that provide for the deployment, management, interconnection, and intercommunication of software application components in embedded and distributed communications systems."²⁸ Software defined radios considered to be SCA compliant are being built now under the auspices of the JTRS Program.

27. Commercial industry adopted the SCA through an industry association called the Software Defined Radio Forum.²⁹ The SDR Forum is an international, nonprofit organization dedicated to promoting the development, deployment, and use of SDR technologies for advanced wireless services and currently has over 100 member organizations. With the SDR Forum, the SCA became an industry-endorsed framework for the evolution and development of software-based radio.

28. The activities of the SDR Forum have increased substantially since its inception. Through international conferences, meetings, participation in standards bodies, and other activities, the Forum has expanded to include a multitude of activities contributing to the development of SDR technologies. They now include such things as technical developments in software portability and security issues, system interfaces, smart antenna technology, waveform developments, network architectures, and references for various software radio implementations. Forum members and participants have also been very active in development of tools for software defined radio design and development such as reference models and automated design tools. The SDR Forum has also established a Special Interest Group for Public Safety to ensure the continued development of SDR within the public safety sector.

29. Recognizing its global implications, the SDR Forum has teamed with and established liaison with other international organizations such as the End-to-End Reconfigurable Radio (E2R) Project Consortium that was established in 2004 by the European Commission. With a membership of over 28 organizations from 10 countries, the E2R Project now includes manufacturers, operators, academia, and research centers throughout Europe. The charter for this project is to "devise, develop and trial the architectural design of reconfigurable devices and supporting system functions to offer an expanded set of operational choices to the users, applications and service providers, operators, and regulators in the context of heterogeneous mobile radio systems."³⁰ The efforts of the E2R consortium are complementing those of the SDR Forum by considering the implementation, reconfiguration, and conformity requirements for modular software-based radio systems.

30. The International Telecommunications Union (ITU) is also beginning consideration of the application of software defined radio concepts in IMT 2000 systems and systems beyond IMT 2000 (systems beyond 3G (B3G)) via Working Party ITUR-8F and is broadening the scope of its software

²⁷ See the DoD JTRS Program web site: <http://jtrs.army.mil/index.htm>.

²⁸ Software Communications Architecture Specification, JTRS-5000, SCA V3.0, August 27, 2004, Prepared by the Joint Tactical Radio System Joint Program Office. Available at: http://jtrs.army.mil/sections/technicalinformation/fset_technical_sca.html.

²⁹ See the SDR Forum web site: <http://www.sdrforum.org/>.

³⁰ See the E2R web site at: http://e2r.motlabs.com/project_overview.

defined radio regulatory policies in Working Party ITUR-8A.³¹ This effort is in the preliminary stages but suggests a worldwide acceptance of software defined radio techniques, policies, and procedures. At present, recommendations are being formulated for submission to the working parties to initiate ITU activity regarding SDRs.

31. An alternative but parallel effort is underway, sponsored by other groups who wish to develop SDRs with an open architecture approach to reconfigurable radio. These include the amateur radio community, kit manufacturers, and the GNU radio project.³² These groups do not use the SCA, but instead favor an architecture open to anyone who may wish to contribute to its evolution via common software development. For example, the GNU radio project is now providing a development circuit board that can be used with a number of openly available software download packages or users can design their own software implementations.

32. Research activities on cognitive radio are ongoing within academia as well, and include universities and research centers around the world. For example, the SDR Forum Technical Conference in November of 2004 included more than 75 organizational participants.³³ Other examples include Virginia Tech's Center for Wireless Telecommunications³⁴ and the University of California Berkeley Wireless Research Center.³⁵ These Centers have initiated active research programs for the development of cognitive radio technologies. One such project is exploring the use of cognitive technology to build public safety radios that are frequency and waveform agile and can adapt to alternative networking requirements and dynamic spectrum requirements.

33. The development of cognitive radio capabilities such as those already mentioned are the result of the rapid advance of various radio technologies – many providing benefits outside of the cognitive radio arena. Digital signal processors, analog-to-digital converters and field programmable gate arrays have provided the basic building blocks as processing platforms for software defined radios. At the same time, new design tools are allowing rapid prototyping and reconfiguration of these basic processors. Other new technologies, such as smart antennas, parallel processing, ad hoc and mesh networking, and multiple-input-multiple-output signal processing techniques are providing new opportunities for alternative and more advanced communications capabilities than simple software radio allows. In addition, new nanoscale technologies, such as the application of 65 nanometer (nm) scale integrated circuits, are fostering potentially revolutionary reductions in scale of devices and increased processing speeds that could permit multiple configurations within SDRs and CRs. Reducing the scale of processors and other microelectronic mechanical systems is continuing and the promise of even further

³¹ See ITU web site at www.itu.int/ITU-R/study-groups/rsg8/rwp8f/index.asp, Document 8A/121-E, 15 SEP, 2004, Annex 9 to WP 8A Chairman's Report; "Working Document Towards a Preliminary Draft New Report: Software Defined Radio in Land Mobile Services".

³² See the GNU Radio web site at: <http://www.gnu.org/software/gnuradio/>.

³³ See <http://www.sdrforum.org/sdr04/papers.html> for a list of presenters at the SDR '04 Technical Conference in November 2004.

³⁴ See the Virginia Tech CWT web site at www.cst.vt.edu.

³⁵ See the UCB web site at <http://bwrc.eecs.berkeley.edu/>.

reductions is still ahead.³⁶ Nanoscale technologies also provide the promise for miniaturization of SDR processors and CR systems. Nanotubes for enhanced conductivity, nanoscale electronics for increasingly smaller scale and faster devices and circuits, and nanoscale electro-optics for enhanced computation and interconnection are the future of radio design. Coincident with hardware developments that aid SDR and CR design, new software developments such as application interfaces, conformance testing procedures, security measures, and reconfiguration management are continuing to provide avenues for more sophisticated, efficient, and reliable software routines that may greatly facilitate the development of increasingly sophisticated cognitive radios.

34. Cognitive radio technologies are the path of evolution of software defined radios from strictly radios whose operating characteristics can be modified via software changes to a fully flexible reasoning-based radios, that is, sophisticated radios that are able to recognize their environment and adopt new operational characteristics based on a reasoned assessment of the environmental and operational etiquette opportunities available to the devices. The flexibility of a fully realized cognitive radio model is based on the model of a six phase cognition cycle where radios apply the "Observe, Orient, Plan, Learn, Decide, Act" phases.³⁷ The process begins with the observation, or awareness, phase during which the radio autonomously acquires information about and recognizes its environment. For example, the radio acquires information regarding its physical environment including time (temporal context), space (geographical context), and frequency (physical interface context). Using this information, a fully flexible cognitive radio is able to process its sensory perceptions, orient itself, and establish a radio presence based on this existing knowledge. This knowledge base provides a foundation for the development of alternative options to planning phase of the cognition cycle. In a fully flexible cognitive radio, the radio will learn based on its past actions and experience, and incorporate that into its deliberations during the next two steps in the cognition cycle - the decide and act phases of the process. These phases are enabled by the software-reconfigurability nature of the radio implementations and allow the radios to use the strategy that the radio reasons³⁸ and arrive at a common operating state with other radios via a managed rendezvous strategy.³⁹ In this context, the devices may even be able to morph to various waveform implementations and thus employ heteromorphic waveform⁴⁰ solutions. After acting in a particular instance, a new generation of intelligence-based radio will then consider the results of its action, and will take into account its learning in future actions. This may lead to flexible implementations as well as new flexible spectrum management opportunities.

³⁶ For a preview of the potential reduction in size of microprocessors, see examples at the Mentor Graphics web site (http://www.mentor.com/products/ic_nanometer_design/techpubs/index.cfm?dt=Simulation) or the Intel web site (<http://www.intel.com/research/silicon/nanotechnology.htm>).

³⁷ Mitola, Joseph, III, "Cognitive Radio for Flexible Mobile Multimedia Communications." IEEE International Workshop on Mobile Multimedia Communications, 1999, 15-17 Nov. 1999, Pg 3 – 10.

³⁸ Instantiation is the actual implementation in hardware and software of a particular set of operating parameters. See the definition at http://searchsmallbizit.techtarget.com/sDefinition/0,sid44_gci212355,00.html.

³⁹ A rendezvous strategy is the reasoning process and protocols or procedures for two transceivers to arrive at common operating parameters such as frequency and synchronization timing.

⁴⁰ A heteromorphic waveform is a signal that can adapt its parameters and characteristics to the electromagnetic spectrum environment or in a purest sense can deviate from a normal, perfect, or mature form; having different forms at different stages of existence.

35. The development of fully cognitive radio technologies is being actively pursued now through programs such as the US Department of Defense Advanced Research Projects Agency (DARPA) Next Generation (XG) Radio Program.⁴¹ For example, Raytheon Corporation, among others, has developed and is testing a prototype XG radio system⁴² that is able to recognize spectrum use opportunities and reconfigure its software radio implementations to take advantage of those opportunities. We believe that the XG Program will be a catalyst for many further developments in cognitive radio technology.

36. The advent of cognitive radios and associated technologies has the potential to initiate a new era in radio frequency spectrum utilization. With radios that are able to recognize spectrum availability and able to negotiate protocols for rapid reconfiguration, these radios will employ software defined radio technologies to change their operational characteristics and open new opportunities for spectrum use. As highlighted in our *Notice*, applications such as dynamic spectrum sharing, interruptible spectrum sharing, and rapidly reconfigurable secondary markets in spectrum use will be attainable with cognitive radios.

B. Enabling cognitive and software defined radio

37. Cognitive and software defined radio technologies have continued to evolve since we adopted rules for software defined radios in 2001. We also have gained greater experience with these technologies, authorizing the first radio under our software defined radio in November 2004.⁴³ Based on these continuing technical developments, our experience, and the comments in the record, we find that certain changes to the rules are appropriate at this time to facilitate the market-based development and deployment of these technologies.

38. In this section, we thus are making certain changes to our current rules and clarifying them in other respects. First we are modifying the definition of software defined radio to include radios that employ software that determines not just the operating parameters, but also the circumstances under which the radio transmits pursuant to those parameters. We clarify that equipment that is designed or expected to be modified by a party other than the manufacturer must be certified as software defined radios and comply with security requirements to prevent unauthorized modifications to the radio frequency operating parameters. We also clarify the security requirements that such equipment must meet.

39. In addition to these changes, we make several other changes to the authorization requirements for software defined radios. We find that the specific rule that requires manufacturers to supply a copy of their radio software (source code) to the Commission upon request is unnecessary because such software is generally not useful for certification review and may have become an unnecessary barrier to entry. In addition, the Commission already has authority to request to request and examine any component (whether software or hardware) of a radio system when needed for certification under Commission rules.⁴⁴ We therefore delete this requirement as discussed below. Further, we clearly

⁴¹ See the XG Program web site at <http://www.darpa.mil/ato/programs/xg/index.htm>.

⁴² See the contract announcement at http://www.prnewswire.com/cgi-bin/micro_stories.pl?ACCT=683194&TICK=RTN4&STORY=/www/story/08-15-2002/0001784186&EDATE=Aug+15,+2002.

⁴³ See *FCC Approves First Software Defined Radio*, News Release dated November 19, 2004.

⁴⁴ See 47 C.F.R. §§ 2.936, 2.943 and 2.946.

define the information about the radio software that must be submitted with applications for software defined radios. Additionally, we allow certification of certain Part 15 unlicensed transmitters that have the technical capability of operating outside Part 15 frequency bands, provided the equipment incorporates features to limit operation to authorized frequencies when used in the United States.

1. Cognitive and software defined radio security

a. Software defined radio definition and applicability of rules

40. To reflect new kinds of conditions sometimes being included in our certification rules, we are broadening the definition of software defined radio to include devices where a software change could change not only the operating parameters of frequency range, modulation type or maximum output power, but also the circumstances under which a transmitter operates in accordance with Commission rules. For example, to make available otherwise unusable spectrum, we have required that certain radio transmitters include a DFS algorithm that further conditions use of spectrum beyond frequency range, modulation type, and maximum output.⁴⁵ We are also changing the rules to require certain equipment to comply with the rules for software defined radios, including the requirement to incorporate security features to prevent unauthorized modifications to the software that controls the RF operating parameters. Specifically, we are requiring equipment in which the software that controls the radio frequency operating parameters is designed or expected to be modified by a party other than the manufacturer to comply with the rules for software defined radios. Because this change is limited to radios that contain RF affecting software that is third party modifiable, we believe that this change will affect only a small subset of equipment available in the marketplace today. We are making no change to the authorization requirements for the vast majority of devices such as cellular/PCS telephones, Wi-Fi equipment and two-way radios where the software that controls the RF operating parameters is not designed or expected to be modified by a party other than the manufacturer.⁴⁶

41. *Background.* The Commission first adopted rules for software defined radios in 2001.⁴⁷ In that proceeding, the Commission defined a software defined radio as “a radio that includes a transmitter in which the operating parameters of frequency range, modulation type or maximum output power (either radiated or conducted) can be altered by making a change in software without making any changes to hardware components that affect the radio frequency emissions.”⁴⁸ This definition was not intended to cover devices such as cellular telephones that use software simply to control functions such as power or frequency within a range approved by the Commission, unless the maximum power or frequency range

⁴⁵ In 2003 the Commission added 255 MHz of spectrum at 5.470-5.725 GHz where U-NII equipment could operate. *See Report and Order* in ET Docket No. 03-122, 18 FCC Rcd 24484 (2003). The rules require U-NII equipment operating in this band to incorporate DFS to protect Federal Government Radar systems that also operate in this band.

⁴⁶ Many transmitters such as cellular and cordless telephones, Wi-Fi devices and two-way radios operate on multiple channels within a predetermined frequency band or bands. The fact that channels can be changed within predetermined bands automatically by software or manually by a user would not necessitate that a device be certified as a software defined radio. However, if the frequency range of a device could be changed by software then that device would have to be certified as a software defined radio if the software was designed or expected to be modified by a party other than the manufacturer.

⁴⁷ *See First Report and Order* in ET Docket No. 00-47, 16 FCC Rcd 17373 (2001).

⁴⁸ *See* 47 C.F.R. § 2.1.

could also be modified by making a change in software.⁴⁹ At the time this definition was adopted, the equipment authorization rules primarily addressed the frequency ranges, modulation types and maximum power or field strength levels of equipment. More recently, certain equipment rules now require features that limit when a radio can transmit even within authorized ranges, such as DFS for U-NII devices.⁵⁰

42. The rules for software defined radios were modeled after the rules for hardware-based equipment, in that a software defined radio will be approved only if the applicant for certification demonstrates that the equipment complies with the technical requirements in one or more specific service(s) or rule part(s) as is required for hardware-based devices. Hardware-based devices are generally not designed to be modified by a party other than the manufacturer. However, the Commission has held that a hardware-based device that can easily be altered to activate a capability of operating in additional frequency bands is subject to equipment certification under the rules that apply in those bands prior to marketing or importation.⁵¹ In the *SDR Proceeding*, the Commission recognized that a software-defined radio might be easier to modify than hardware-based devices. As a matter of policy, the Commission wanted additional assurances that manufacturers of software-based equipment would take steps to prevent abuses, so it adopted a requirement that a device that is certified as a software defined radio must incorporate a means to ensure that only software that is part of an approved hardware/software combination can be loaded into a radio, and the software must not allow the radio to operate with parameters outside of those that were approved.⁵² To eliminate the need for manufacturers to file a complete new application and re-label equipment when software changes that affect the RF operating parameters are made after the initial equipment approval, the Commission established a streamlined authorization procedure for changes to the software that controls these parameters.⁵³ The rules require an applicant for equipment authorization, or the grantee or other party responsible for the compliance of the equipment, to supply a copy of the software that controls the RF operating parameters to the Commission upon request.⁵⁴ The rules for software defined radios are permissive; meaning that a manufacturer does not have to declare that a device is a software defined radio in the application for certification, even if the device meets the definition.

⁴⁹ See *Notice of Proposed Rule Making* in ET Docket No. 00-47, 15 FCC Rcd 24442, 24450 (2000).

⁵⁰ See 47 C.F.R. § 15.407(h).

⁵¹ See *In the Matter of Pilot Travel Centers, L.L.C., Knoxville, Tennessee, Notice of Apparent Liability for Forfeiture*, 19 FCC Rcd 23113, 23114 (2004). In this forfeiture proceeding, the Commission issued a Notice of Apparent Liability for violations of Section 302(b) of the Communications Act of 1934, as amended, and Section 2.803(a)(1) of the Commission's rules for marketing unapproved radio transmitters. The transmitters in question were marketed as amateur equipment, which is normally exempt from a certification requirement. However, the transmitters had the capability of being easily altered to operate on frequency bands in the Citizen's Band (CB) Radio Service, so the Commission held that they met the definition of a CB transmitter under Section 95.603(c) of the rules, which requires such transmitters to be certified before they can be imported into or marketed within the United States. The equipment being marketed, which complied with all requirements for amateur equipment, was capable at transmitting at power levels well above those permitted for CB transmitters.

⁵² See 47 C.F.R. § 2.932(e).

⁵³ See 47 C.F.R. § 2.1043(b)(3).

⁵⁴ See 47 C.F.R. § 2.944.

43. Of course, many radios that meet the definition of a software defined radio are not designed or expected to be modified by a party other than the manufacturer. For instance, many radios incorporate software on chips that can not be easily reprogrammed or replaced by a user. However, some newer radios are being designed so that the software that controls the radio frequency operating parameters can be modified or replaced after manufacture by a party other than the manufacturer. Common techniques employed include a keypad, over-the-air, or through an interface that connects to a computer or other programming device. In the *Notice*, we sought comment on the need to require equipment in which the RF affecting software is user modifiable to comply with the requirements for software defined radios, including the requirement to incorporate security features.⁵⁵ Additionally, we sought comment on the types of devices to which this requirement should apply, including how the rules should distinguish between transmitters that must be certified as software defined radios and those that need not be.⁵⁶

44. *Comments.* A number of parties support a requirement for devices to comply with the rules for software defined radios if the software and operating parameters can be easily changed post-manufacture and/or that pose a high risk of causing interference to licensed services such as public safety.⁵⁷ Intel states that those devices that use software defined radio as a manufacturing technique and are not intended to be modified in the field should not be required to be declared as software defined radios, and that the Commission should impose requirements on only those devices where the manufacturer intends to allow modifications in the field.⁵⁸ Vanu, Inc., a manufacturer of software defined radios, believes that mandatory certification as software defined radios may be desirable when harmful interference may result from a foreseeable modification to the device's software by a third party. It states that the Commission could adopt security requirements that are not limited to radios that meet the definition of software defined radios.⁵⁹ The National Public Safety Telecommunications Council and the SDR Forum believe that the Commission's concern should not be that a radio could be reprogrammed on an individual basis because the number of radios potentially affected that way would not be significant.⁶⁰ They state that the Commission's concern should be that large numbers of radios could be remotely modified simultaneously (e.g., through a cellular network or over the Internet), and support a requirement to incorporate security features in all software defined remotely programmable radios that are capable of transmitting in public safety or restricted bands, regardless of whether they are declared as software defined radios.⁶¹ Cingular/Bellsouth believe that the Commission should apply security requirements to all software defined remotely programmable transmitting devices whether they are declared as software defined radios or not.⁶² Cisco states that devices that can be reprogrammed in the field by the end user should be treated as software defined radios for equipment authorization purposes,

⁵⁵ See *Notice* at 26892.

⁵⁶ *Id.*

⁵⁷ See Intel comments at 5, Vanu comments at 4, the NPSTC comments at 19, Cingular/Bellsouth comments at 28, Cisco comments at 12 and SDR Forum comments at 6-7.

⁵⁸ See Intel comments at 5.

⁵⁹ See Vanu comments at 4.

⁶⁰ See NPSTC comments at 19 and SDR Forum comments at 6.

⁶¹ See NPSTC comments at 19 and SDR Forum comments at 7.

⁶² See Cingular/Bellsouth comments at 28.

while those devices that cannot be reprogrammed by the end user need not be authorized as software defined radios.⁶³

45. Sirius/XM and Nextel Partners also support mandatory certification as software defined radios. Sirius/XM state that mandatory software defined radio registration is a rational approach to protecting licensed services and places the burden to avoid interference on the unlicensed and not the licensed user.⁶⁴ Nextel Partners state that software defined radio manufacturers should be required to identify their technologies as such and should not be permitted to avoid Commission-imposed requirements by mischaracterizing or failing to fully declare the capabilities of their devices.⁶⁵

46. Several parties oppose a requirement to certify certain equipment as software defined radios.⁶⁶ The Wi-Fi Alliance expresses concern about the added burden on manufacturers and Commission staff if mandatory software defined radio categorization is imposed on hundreds of WiFi device applications.⁶⁷ Motorola opposes any rule requiring it to declare whether a device constitutes a software defined radio, stating that the definition of software defined radio is too broad to ensure that certain devices are not improperly included. Motorola further argues that such a requirement could improperly restrain the development of certain technologies.⁶⁸ Ericsson and TIA also oppose any requirement that manufacturers or importers declare certain equipment as software defined radios, stating that the current rules provide adequate safeguards against unauthorized modifications to software defined radios.⁶⁹ They further state that a mandatory software defined radio declaration in the filing for some devices could be a disincentive to the deployment of software defined radios and burden industry by inhibiting robust development of an efficient manufacturing technique.⁷⁰

47. *Discussion.* We conclude that it is necessary to modify our rules to help ensure that certain radios incorporating software cannot be easily modified on an unauthorized basis and cause harmful interference or otherwise violate our rules. Specifically, to conform the definition of software defined radio to the evolving nature of our certification requirements, we are first modifying that definition to include radios that employ software that determines not just the operating parameters, but also the circumstances under which the radio transmits pursuant to those parameters. Second, we are requiring software defined radios whose relevant RF affecting software is designed or expected to be modified by a party other than the manufacturer to comply with the rules for software defined radios, including the requirement to incorporate security features (further discussed below) to prevent unauthorized modifications to the software.

⁶³ See Cisco comments at 12.

⁶⁴ See Sirius/XM reply comments at 5.

⁶⁵ See Nextel Partners comments at 8.

⁶⁶ See Wi-Fi Alliance comments at 5, Motorola comments at 19, Ericsson comments at 20 and TIA comments at 8.

⁶⁷ See Wi-Fi Alliance comments at 5.

⁶⁸ See Motorola comments at 19.

⁶⁹ See Ericsson comments at 20 and TIA comments at 8.

⁷⁰ See Ericsson comments at 20 and TIA comments at 8.

48. We modify our definition of software defined radio because, under recent rules, certain software changes that do not directly affect the technical operating parameters affect whether the device can be certified under our rules. The direct effects are addressed in the current definition of a software defined radio: frequency range, modulation type or maximum output power (either radiated or conducted).⁷¹ Our rules, however, now sometimes require additional radio functions such as DFS to prevent interference to other users. Even though these functions are being implemented and controlled by software in a radio, they do not currently fall within the definition of a software defined radio. In its comments, Vanu suggested that the Commission could consider security requirements that are not limited to radios that meet the definition of software defined radios. We agree with Vanu that we should not limit our consideration of radio security issues only to those radios within the current software defined radio definition.

49. Consistent with the above, we are changing the definition of software defined radio to address software changes that directly or indirectly affect the compliance of a device with the Commission's rules. The modified definition will read as follows.

Software defined radio. A radio that includes a transmitter in which the operating parameters of frequency range, modulation type or maximum output power (either radiated or conducted), or the circumstances under which the transmitter operates in accordance with Commission rules, can be altered by making a change in software without making any changes to hardware components that affect the radio frequency emissions.

50. We are also changing the applicability of our rules to address software defined radios with relevant software that is designed or expected to be modified by a party other than the manufacturer. If a radio is not certified as a software defined radio, a manufacturer is not required to demonstrate in the equipment certification process that it incorporates features designed to prevent unauthorized changes to the software that would permit violation of Commission rules the equipment's certification, thus increasing the risk of interference to authorized radio services. We find that such a showing is in the public interest when a radio's RF-affecting software is designed or expected to be modified by a third party other than the manufacturer. In addition to minimizing the potential for unauthorized modifications to software defined radios, these changes will benefit manufacturers by allowing them to take advantage of the streamlined Class III permissive change procedure when they develop revised software that affects the RF operating parameters of the radio.⁷²

51. We find that the rules we are adopting that require the certification of certain radios as software defined radios will not be unduly burdensome on manufacturers or restrain the development of technology. Only a relatively small number of radios will be affected by this requirement because most RF affecting radio software is not designed or expected to be modified by a party other than the manufacturer, and we are not changing the rules for radios that are not designed or expected to be modified by a party other than the manufacturer. Thus, there will be no change to the authorization requirement for the vast majority of devices including cellular/PCS telephones, land mobile transceivers

⁷¹ See 47 C.F.R. § 2.1.

⁷² The Class III permissive change allows a manufacturer to obtain approval for changes in the software that control the operating parameters in a software defined radio without the need to file a complete certification application or change the FCC identification number on the device. The Class III change is permitted only for radios that were declared as a software defined radio at the time of the initial certification. See 47 C.F.R. § 2.1043(b)(3).

and Wi-Fi equipment, provided the software that directly or indirectly controls the RF emissions of these devices is not designed or expected to be modified by a party other than the manufacturer. Also, manufacturers of radios that are software modifiable typically already take steps to prevent unauthorized modifications to the software in a radio, so we expect that only rarely will manufacturers have to make significant design changes to comply with the security requirements. In addition, as discussed below, we are adopting changes to simplify the information that must be submitted with an application for a software defined radio. Finally, we find that the requirements we are adopting are consistent with the Commission's authority under Section 302 of the Communications Act to make reasonable regulations, consistent with the public interest, which govern the interference potential of radio frequency devices.⁷³

52. We find that the standard we are adopting adequately protects against interference to other users. We disagree with the commenters who argue that only radios that can be remotely modified in large numbers should be required to be certified as software defined radios. We first find that this definitional standard to be too difficult to apply. We also note that a radio that lacks security features to prevent unauthorized changes to the RF operating parameters could be easily modifiable to operate in unauthorized bands, and therefore has a high potential to interfere with authorized users in many different bands, including public safety bands. We therefore find that the requirement to certify certain radios as software defined radios should apply to all radios which are software modifiable by the user, not just those which could be remotely modified in large numbers.

53. *Permissive changes to software defined radios.* We are modifying the Class III permissive change rule, Section 2.1043(b)(3), to make the wording consistent with the modified definition of software defined radio adopted above. Additionally, we are setting forth a policy for permissive changes to radios that were approved before the effective date of the rules adopted herein. Specifically, when a grantee wishes to make a permissive change to a previously approved device, the device will be continue to be classified in the same manner that it was at the time it was originally certified, *i.e.*, software defined or non-software defined radio. Thus, a device that was approved as a non-software defined radio before the rules adopted herein become effective will not have to be re-certified as a software defined radio even if it meets the new standard for mandatory certification as a software defined radio. A device that was certified as a software defined radio will continue to be treated as such when a request for a permissive change is filed. Parties should note that we are not changing the requirement that Class III changes are permitted only for software defined radios in which no Class II changes have been made from the originally approved device.

b. Security requirements for software defined radios

54. We are clarifying the requirements in the rules that are intended to prevent unauthorized changes to the operating parameters of software defined radios. The Commission's equipment approval rules currently require that manufacturers take steps to ensure that only software that has been approved with a software defined radio can be loaded into such a radio.⁷⁴ The current rule states that the software must not allow the user to operate the transmitter with frequencies, output power, modulation types or other parameters outside of those that were approved.⁷⁵ Manufacturers may use authentication codes or

⁷³ See 47 U.S.C. § 302.

⁷⁴ See 47 C.F.R. § 2.932(e).

⁷⁵ *Id.*

any other means to meet these requirements, and must describe the methods in their application for equipment authorization.⁷⁶

55. In the *Notice*, we sought comment on whether the rules provide adequate safeguards against unauthorized modifications to software defined radios or whether more explicit security requirements are necessary, such as requiring electronic signatures in software to verify the software's authenticity.⁷⁷ We also sought comment on whether there should be limits to a manufacturer's liability in the event that reasonable security methods ultimately are broken, specifically, whether a manufacturer would be deemed compliant with the rule requiring security measures to prevent unauthorized software modifications, if it has taken measures that are "commercially reasonable" in light of standards employed in the software defined radio industry at the time, provided it has not marketed a device containing a known software vulnerability.⁷⁸

56. Commenters are generally supportive of the Commission's current requirements that allow the security of software defined and cognitive radios to be addressed by industry and state that this approach allows industry to incorporate new and more advanced security measures into equipment without the need for Commission action.⁷⁹ Dell believes that, in addition, there should be limitations on the liability of a manufacturer that meets or exceeds an industry standard for security methods in the event that equipment is found to be modifiable by end users. By contrast, Intel believes this approach would be counterproductive because such a rule could encourage manufacturers to design equipment to meet a standard that may not address the actual threat of modifications to a specific device.⁸⁰

57. We find that the current approach that manufacturers take steps to prevent unauthorized changes to the software in a radio, but does not require the use of specific security measures, is the most appropriate method to ensure the security of software defined radios. This approach allows manufacturers to respond to improvements in security technology more quickly and with the best solutions for a particular product because no Commission action is necessary to permit manufacturers to use new security technologies. Therefore, we are maintaining the current security requirement. The record shows that manufacturers are aware of the need to incorporate security measures in software defined radios and are in fact doing so.⁸¹ We note that NTIA has recommended that, as a long term goal, we consider requiring "Protection Profiles" – an approach currently under consideration in the SDR Forum – as part of the equipment certification process for software defined radios.⁸² After industry progresses further in its deliberations, we may consider the possible applicability of Protection Profiles,

⁷⁶ *Id.*

⁷⁷ See *Notice* at 26894.

⁷⁸ *Id.*

⁷⁹ See AT&T Wireless comments at 16-18, Wi-Fi Alliance comments at 6, ITI comments at 8-9, Motorola comments at 20, Cisco comments at 12, Dell comments at 4, Intel comments at 7 and SDR Forum comments at 7.

⁸⁰ See Dell comments at 4 and Intel comments at 7.

⁸¹ See Cingular/BellSouth comments at 28, Dell comments at 4, Intel comments at 5 and ITI comments at 7.

⁸² See NTIA comments at 33-36.

or certain concepts of Protection Profiles, to equipment certification in a future proceeding that addresses the security of software defined and cognitive radios.

58. Our security requirements for software defined radios give manufacturers flexibility to determine the appropriate security measures for a device. However, manufacturers also have the responsibility to choose security measures that can not be easily defeated by unintended parties. In the event that a software defined radio is found to be easily modifiable by end users, we would expect the responsible party as defined by our rules to immediately cease marketing the equipment and to take steps to ensure that future production of the equipment complies with the rules. Any potential forfeiture for non-compliance with the software defined radio security requirements would be considered on a case-by-case basis, taking into account all relevant factors, in the same manner as forfeitures are considered for non-compliant hardware-based equipment. In determining whether to issue any forfeiture penalties for a non-compliant device, the Commission takes into account the nature, circumstances, extent and gravity of the violations and, with respect to the violator, the degree of culpability, any history of prior offenses, ability to pay, and such other matters as may be relevant and appropriate.⁸³ The Commission has specific guidelines for assessing forfeitures, but may issue higher or lower forfeitures than provided in the guidelines, issue no forfeiture at all, or apply alternative or additional sanctions as permitted by statute.⁸⁴

59. We decline to establish specific limitations on the responsible party's liability for a device that incorporates specific type(s) of security measures in the event that it is later determined that unauthorized modifications can be easily made to the radio frequency operating parameters of the device. As discussed above, the responsible party's liability for a non-compliant device is most appropriately determined on a case-by-case basis. Further, we agree with Intel that such an approach could be counterproductive because manufacturers would tend to design equipment to incorporate specific security features and may have little incentive to design equipment with robust security features, especially where more secure features add cost to a device. However, the Commission may consider compliance with industry security standards as a factor in determining the responsible party's liability.

60. We are simplifying the structure of the rules for software defined radios by moving the security requirements for software defined radios from Section 2.932(e) into Section 2.944. Section 2.944 currently contains a requirement for parties to submit a copy of radio software to the Commission upon request. As discussed below, we are changing that requirement as well as the applicability of the security requirements for software defined radios. We are placing the requirements for software defined radios into a single rule section, Section 2.944, for easier reference. We are also modifying Section 2.1033, which lists the information to be included in an application for certification, to make clear that an application for certification of a software defined radio must include the information specified in the revised Section 2.944.

61. As part of the revisions to Section 2.944, we are providing specific examples of the types of security measures that the Commission may consider to be acceptable for preventing unauthorized modifications to equipment.⁸⁵ These examples are intended only to provide guidance to industry, and the

⁸³ See 47 C.F.R. § 1.80(b)(4).

⁸⁴ *Id.*

⁸⁵ See 47 C.F.R. § 2.944. This section previously addressed only the requirement to submit a copy of radio software upon request. The issue of the submission of radio software is also addressed in this *Report and Order*.

use of one or more of these methods in a particular device should not be construed to limit a manufacturer's liability or responsibility to take appropriate corrective action in the event that parties other than the manufacturer are able to make unauthorized modifications to a device. This section will state that manufacturers may use any reasonable means to prevent impermissible modifications to the radio software including, but not limited to, the following and must describe the method(s) used for a particular device in the application for certification:

- The use of a private network that allows only authenticated users to download software.
- Coding in hardware that is decoded by software to verify that new software can be legally loaded into a device.
- Electronic signatures in software

c. Amateur equipment and D/A converters

62. In the *Notice*, we proposed to exempt manufactured software defined radios that are designed to operate solely in amateur bands from any mandatory declaration and certification requirements, provided the equipment incorporates features in hardware to prevent operation outside of amateur bands.⁸⁶ We also sought comment on the need to restrict the mass marketing of high-speed digital-to-analog (D/A) converters that could be diverted for use as radio transmitters.⁸⁷ ARRL and the National Public Safety Telecommunications Council state that it is not practical to incorporate features in the hardware of an amateur transceiver to prevent transmissions outside of amateur bands.⁸⁸ Intel, ITI, Cisco, Raytheon, ARRL and the Electronic Frontier Foundation oppose regulating the marketing of high speed D/A converters, generally stating that such a requirement would be burdensome, increase costs to consumers and not necessary because these devices do not pose a risk of interference.⁸⁹ No parties have provided any information that shows that software programmable amateur transceivers or high-speed D/A converters present any significantly greater risk of interference to authorized radio services than hardware radios. Therefore, we decline to adopt any new regulations for amateur transceivers or D/A converters at this time. However, we note that certain unauthorized modifications of amateur transmitters are unlawful,⁹⁰ and may revisit both of these issues in the future if misuse of such devices results in significant interference to authorized spectrum users.

2. Submission of radio software

63. As described below, we are eliminating the rule that a manufacturer supply radio software (source code) to the Commission upon request because such software is generally not useful for

⁸⁶ See *Notice* at 26893.

⁸⁷ See *Notice* at 26893.

⁸⁸ See ARRL comments at 9 and NPSTC comments at 20.

⁸⁹ See Intel comments at 7, ITI comments at 6, Cisco comments at 16, Raytheon comments at 2, ARRL comments at 17, and EFF comments at 6.

⁹⁰ See para 44 and note 53, *supra*.

certification review and may have become an unnecessary barrier to entry.⁹¹ We are also requiring applicants for certification of software defined radios to supply a high level operational description of the software that controls the RF operating parameters.

64. In the *Notice*, we proposed to make these changes because of the expected complexity and variations in the programming languages of the software used to control radio operating parameters, stating that examining radio software is unlikely to be an effective way to determine whether unauthorized changes have been made to a device.⁹² We stated that a high level description of the radio software and flow diagram of how the software works would be more useful in understanding the operation of a device and its security measures than a copy of the software.

65. Parties generally support requiring the submission of a software description and flow diagram with a certification application rather than actual radio software.⁹³ Motorola agrees that receiving actual software would not prevent unauthorized changes because source code is compiled before loading and additional changes are made after the loading process, and that the requirement is superfluous because the rules require the equipment to comply with technical requirements and require manufacturers to provide sample devices and records upon request.⁹⁴ It requests that the Commission grant the material full confidential treatment because it would be highly proprietary software information and real competitive harm could be caused to a manufacturer if competitors were to access it.⁹⁵ TIA believes that the Commission should institute appropriate safeguards to ensure that flow diagrams are not made available to the general public.⁹⁶ The SDR Forum, Cingular/Bellsouth and the National Public Safety Telecommunications Council recommend that the Commission permit Telecommunication Certification Bodies (TCBs) to certify software defined radios because applicants have confidence that a TCB will keep information about devices confidential.⁹⁷ The Wi-Fi Alliance supports removing the requirement to supply source code upon request, but does not believe there is a need to supply a software description and flow diagram because such a description will not realistically assist the Commission or TCBs in judging if a device meets the applicable authorization requirements.⁹⁸ It states that if a requirement for a flow diagram is created then it should be limited to explaining the protection measures

⁹¹ See 47 C.F.R. § 2.944. Failure to comply within 14 days may be grounds for denial of equipment authorization or monetary forfeitures. See also 47 C.F.R. § 2.1043(b)(3).

⁹² See *Notice* at 26891.

⁹³ See TIA comments at 8, Motorola comments at 19-20, Vanu comments at 3, Technology Companies reply comments at 11, Wi-Fi Alliance comments at 8 and Intel comments at 3.

⁹⁴ See Motorola comments at 19.

⁹⁵ See Motorola comments at 20.

⁹⁶ See TIA comments at 8.

⁹⁷ See SDR Forum comments at 8, Cingular/Bellsouth comments at 29 and National Public Safety Telecommunications Council comments at 12. TCBs are private sector bodies that have been designated to approve radio frequency equipment in the same fashion as the Commission.

⁹⁸ See Wi-Fi Alliance comments at 8.

implemented to prevent unauthorized modifications to a device's software rather than an open-ended, comprehensive explanation of the device's software architecture.⁹⁹

66. Cingular/Bellsouth believe that the Commission should require applicants to submit source code for devices to ensure that certain operational characteristics are maintained within the scope of the authorization and that the transmitting device can not be misappropriated for improper operation.¹⁰⁰ They state that if the Commission deletes the current requirement, it must ensure that software changes affecting RF emission characteristics of devices do not cause interference to licensed operators.¹⁰¹

67. We are removing the requirement that an applicant for authorization of a software defined radio or the grantee or other party responsible for the compliance of a software defined radio submit a copy of the software that controls the radio frequency operating parameters upon request. We find that a copy of software source code is generally not be a useful aid in determining whether unauthorized changes have been made to the operating parameters of a device because software changes that have no effect on these parameters are frequently made by manufacturers. We also are concerned that this specific rule may be overly burdensome because we have observed that some equipment that could be authorized under the rules for software defined radios is not being authorized under these rules.¹⁰² The fact that the software in a device being marketed may differ somewhat from software previously supplied to the Commission would not necessarily indicate that any unauthorized changes have been made to a device's RF affecting operating parameters. In the event that questions arise about the compliance of a particular device, the Commission has the authority to request and examine any component (whether software or hardware) of a radio system when needed for certification under Commission rules without the need for a specific requirement to submit radio software. Grantees of equipment certification are required to maintain records of equipment specifications and any changes that may affect compliance and must make these records available for inspection by the Commission.¹⁰³ Further, the party responsible for the compliance of the device or any party who markets the device must supply a sample of the device to the Commission upon request.¹⁰⁴

⁹⁹ *Id.*

¹⁰⁰ See Cingular/Bellsouth comments at 26.

¹⁰¹ *Id.*

¹⁰² For example, some manufacturers have indicated to Commission staff that they have obtained approval for U-NII transmitters in which additional frequency bands can be added by replacing software drivers, but these transmitters were not certified as software defined radios. The Commission made an additional 255 MHz of spectrum available at 5.470-5.725 GHz where U-NII equipment could operate in the *Report and Order* in ET Docket No. 03-122, 18 FCC Rcd 24484 (2003). The rules require U-NII equipment operating in this band to incorporate DFS to protect Federal Government Radar systems that also operate in this band. The Commission, the National Telecommunications & Information Administration (NTIA), the Department of Defense (DOD) and the industry are continuing to develop the testing methodologies for ensuring that DFS adequately protects Federal Government radar systems, so measurement procedures for certifying U-NII devices containing DFS capabilities have not yet been finalized. Thus, U-NII devices can not yet be certified to operate in the new frequency band.

¹⁰³ See 47 C.F.R. §§ 2.936(a) and 2.938(a). We note that Sections 303(e) and Section 4(i) of the Communications Act continue to give the Commission authority to request data that will assist us in carrying out our responsibilities under the Act. See 47 U.S.C. §§ 154(i) and 303(e).

¹⁰⁴ See 47 C.F.R. §§ 2.931, 2.936(b), 2.943, 2.945 and 2.946.